Original Article

Maximum Heart Rate in Brazilian Elderly Women: Comparing Measured and Predicted Values

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Summary

Objective: **This study sought to compare maximum heart rate (HRmax) values measured during a graded exercise test (GXT) with those calculated from prediction equations in Brazilian elderly women.**

Methods: **A treadmill maximal graded exercise test in accordance with the modified Bruce protocol was used to obtain reference values for maximum heart rate (HRmax) in 93 elderly women (mean age 67.1 ± 5.16). Measured values were compared with those estimated from the "220 - age" and Tanaka et al formulas using repeated-measures ANOVA. Correlation and agreement between measured and estimated values were tested. Also evaluated was the correlation between measured HRmax and volunteers' age.**

Results: **Results were as follows: 1) mean HRmax reached during GXT was 145.5 ± 12,5 beats per minute (bpm); 2) both the "220 - age" and Tanaka et al (2001) equations significantly overestimated ($p < 0.001$) HRmax by a mean difference of 7.4 and 15.5 bpm, respectively. 3) age was significantly ($p < 0,001$) and inversely related to measured HRmax.**

Conclusion: **Based on these results, it can be concluded that both prediction equations significantly overestimated HRmax measured during maximal GXT in Brazilian elderly women, a finding that may have important implications when prescribing exercise intensity for this population. In addition, HRmax was inversely related to the volunteers' age, suggesting that the chronotropic reserve continues to decline after age 60.**

Key words: **Heart rate; exercise test; women; aged; exertion.**

Introduction

Heart rate can be easily and non-invasively measured, which makes it widely used to assess cardiovascular responses to exercise and its recovery from stress, as well as to study sympathoadrenal reactivity during cognitive tests[1]. During a graded exercise test, HR rises progressively and proportionally to the amount of work performed[2], until a maximum value is reached that cannot be surpassed despite subsequent increases in workload. This point is called maximum heart rate (HRmax), and is usually regarded as the upper limit of the central cardiovascular system[3].

HRmax is an important physiological variable used as a criterion to assess maximal exertion during graded exercise tests[4] (GXT). Moreover, this variable is likely to be the most used measure as a basis for prescribing exercise intensities, and it is usually expressed in percentage of maximal heart rate or heart rate reserve (HRmax minus resting HR[3,5]). Even though chronotropic reserve is markedly influenced by age, being inversely related to it, this variable is also affected by other factors, such as the type of ergometer used, resting HR, smoking status, gender, and body composition[6,7,8].

Additionally, the use of drugs with negative chronotropic action, especially beta-blockers, decreases significantly HRmax in young people[9,10] and adults alike[11]. The influence of these variables makes it difficult to establish an accurate approach to estimate HRmax, which may have implications for prescribing exercises based on age-predicted values, particularly for elderly subjects, because cardiovascular diseases are more prevalent in old age.

The "220 - age" prediction equation is probably the most commonly method used to estimate HRmax and seems to be originally reported by Fox et al[12]. It has been extensively used in elderly Brazilians, albeit its accuracy and applicability warrant further studies involving a sample of this population. More recently, Tanaka et al[13] developed another regression model (208 - 0.7 x age) to estimate the same variable, the values of which differ significantly from the traditional equation. When both equations are compared, the traditional "220 - age" equation overestimates HRmax in young adults, yields the same values as those obtained by Tanaka's regression in forty-year old subjects and, from that age on, underestimates HRmax as compared with the "208 - 0.7 x age" equation. Both formulas need to be better studied in Brazilian elderly women; consequently, its application has been called into question. The aim of this study is two-fold: to compare maximum heart rate (HRmax) values measured during graded exercise testing (GXT) with those derived from the above-mentioned prediction equations in Brazilian elderly women and to correlate the volunteers' age with measured HRmax.

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Manuscript received August 19, 2006; revised manuscript received September 28, 2006; accepted November 10, 2006.

Methods

Study sample - The study sample was recruited from an outreach project developed by the University, which offers physical activities, medical and psychological assistance, nutritional assessment, and English classes to the local elderly community. After initial screening, a total of 93 apparently healthy Brazilian elderly women from 60 to 81 years of age (mean age 67.12 ± 5.16 years) volunteered to participate in this investigation. Exclusion criteria were the following: 1) absolute or relative contraindication to exercise stress testing; 2) Body Mass Index above 35.0 kg/m^2 or below 20.0 kg/m^2; 3) subjects using beta-blockers and/or calcium-channel blockers; 4) electrocardiographic changes suggestive of major myocardial ischemia or cardiac arrhythmias during examination; 5) subjects who did not reach volitional exhaustion 6) smoking status; 7) non-Brazilian subjects; and 8) age under 60. All of them performed GXT for cardiovascular assessment and aerobic exercise prescription.

All participants signed an informed consent including information about the voluntary nature of their participation, the risks and benefits of the procedures, and the right to withdraw from the study at any moment. The protocol for data collection was approved by the University's Research Ethics Committee. Study sample physical characteristics, time to exhaustion, and estimated VO_2max are summarized in Table 1.

Table 1 - Sample characteristics (n = 93)

Variable	Mean ± Standard Deviation	Variation
Age (years)	67.12 ± 5.16	60 to 81
Body weight (kg)	66.66 ± 9.29	43.7 to 88.8
BMI (kg/m^2)	27.68 ± 3.48	20.54 to 34.42
Test duration (minutes)	11.37 ± 1.67	7.50 to 15.10
Estimated maximal VO_2 (ml.kg-1.min-1)	22.24 ± 4.93	12.25 to 35.35

BMI - Body Mass Index; VO_2 - oxygen uptake.

Procedures - All procedures were performed at the Laboratório de Avaliação Física e Treinamento (LAFIT) of the University (Physical Fitness and Training Laboratory). Body mass was measured to the nearest 0.1 kg using a digital scale (2006 PP TOLEDO, Brazil), with volunteers wearing light clothes and no shoes. Body height was measured to the nearest 0.1 cm using a wall-mounted stadiometer (CARDIOMED, Brazil). Body mass index (BMI) was calculated by dividing body weight by height squared (kg/m^2). All tests took place in a temperature-controlled exercise testing room maintained at about 22°C with all the equipment and medications needed to provide emergency care.

Volunteers' HRmax reference values were measured during a GXT performed on an electronic treadmill (Super ATL, Imbramed, Brazil) under the supervision of a cardiologist. All study participants abstained from caffeine and physical exercise for 12 and 24 hours, respectively, prior to reporting to the laboratory. Volitional exhaustion was established as the criterion for GXT termination, and toward the end of examination the volunteers were given verbal encouragement. Heart rate was continuously monitored by electrocardiography (Digital ECG, Micromed, Brazil) according to the following logical sequence: at rest (standard 12-lead ECG), throughout the exercise and six-minute recovery period (three-lead ECG: leads CM5, D2M e V2M); values were expressed in beats per minute (bpm). Lead CM5 was defined as rhythm lead.

Heart rate was determined automatically by calculating the moving mean of RR intervals of the eight last complexes, updated at every systole. In short, mean HR of the last eight beats = 1 / (R-R)m x 60, where (R-R)m is the mean value of the last eight intervals in seconds. Electrocardiographic monitoring was performed using the Ergo PC for Windows (Micromed, Brasil) software, which controlled treadmill speed and grade through a computer interface. After checking for potential interferences in ECG tracings and extrasystoles, maximum heart rate was defined as the highest value recorded during the test.

Treadmill testing was performed according to the modified Bruce protocol (two stages of 2.7 km/h with 0% and 5% grades, respectively, followed by the standard Bruce protocol), after history taking, cardiovascular evaluation (resting ECG and blood pressure), and a warm-up period including stretching exercises and a one-minute walk at 1.5 km/h. The protocol consists of three-minute stages and increments in exercise intensity, as shown in Table 2. At the end of each stage, blood pressure was measured with a mercury sphygmomanometer, and the subjective perception of exertion was monitored through direct communication by using the Borg scale[14].

Table 2 - Increments in speed and grade of the protocol used: Modified Bruce

Stages	Stage length (min)	Speed (km/h)	Grade (%)
1	3'	2.7	0.0
2	3'	2.7	5.0
3	3'	2.7	10.0
4	3'	4.0	12.0
5	3'	5.5	14.0
6	3'	6.8	16.0

Stage length is presented in minutes; speed, in kilometers per hour; and grade, in percentage.

Cardiorespiratory fitness was evaluated by estimating maximal oxygen uptake (VO_2max) relative to body weight, through the workload achieved during GXT and according to the walking equation proposed by the American College of Sports Medicine[4], in which VO_2 (ml.kg^{-1}.min^{-1}) = 0.1 x Speed (in meters per minute) + 1.8 x Speed x Grade + 3,5. All participants were verbally informed about GXT procedures and instructed to exercise until they felt unable to continue.

HRmax estimate - The "220 – age" and "208 – 0.7 x age" equations[13] were used to calculate predicted HRmax; these formulas were chosen due to their wide use and the debate about their applicability. The "220 –age" equation is generally erroneously linked to Karvonen[6]; however, its original publication is not exactly known. Nonetheless, this is probably the most used strategy for HRmax prediction, including in studies involving subjects of both genders[15-18].

Statistical treatment - Descriptive statistics were used for all the variables, and data were presented as means and standard deviations.The following statistical analyses were performed: the Kolmogorov-Smirnov test for normal distribution of data; repeated-measures analysis of variance (ANOVA) for differences between HRmax reference values predicted by both equations; *post hoc* Bonferroni test for relevant differences between means; linear regressions and Pearson's correlation coefficient to analyze the relationship between the predicted and actual HRmax measured. The same strategy was adopted to assess the relationship between age and maximum HR measured during GXT. The Bland-Altman test[19] for agreement between measured and predicted values was applied. The statistical significance level was set at $p< 0.05$. All analyses were performed using SPSS PC for Windows, version 11.0, and Microsoft Excel 2003.

Results

Initially, 144 subjects underwent graded exercise testing, but only 93 were eligible for the subsequent analyses. The others were excluded for the following reasons: fifteen were younger than 60; four showed evidence of myocardial ischemia, two had blood pressure hyperreactivity (systolic blood pressure > 220 mmHg), and one experienced complex ventricular arrhythmia during exercise. Nine other volunteers were on beta-blockers, and one reported thoracic pain during examination. Four volunteers had BMI < 20 kg/m^2, and 15 other had BMI > 35 kg/m^2. Exploratory data analysis revealed that all variables were normally distributed, and no outlier was detected (z-scores < ± 3.0).Accordingly, the 93 volunteers were included in the subsequent analyses. In this study, all tests were terminated due to exhaustion, and no complications were observed either during the exertion or recovery phase.

Table 3 presents means and standard deviations of resting HR, as well as maximum heart rate measured at the end of the GXT. It also depicts HRmax derived from prediction equations.

Comparison between measured HRmax and those produced by prediction equations are shown in Table 4. Both the "220-age" equation and that proposed by Tanaka et al[13] overestimated significantly ($p < 0.001$) the HRmax (measured) of the elderly women by a mean difference of 7.4 bpm and 15.5 bpm, respectively. Heart rate reached at exhaustion was, on average, 95.2 ± 7.5 % of the HRmax predicted by the "220 - age" equation. In addition, HRmax values obtained by applying the "208 – 0.7 x age" equation[13] were statistically significantly overestimated ($p < 0.001$), when compared to those derived from the "220 - age" equation, with a mean difference of 8.1 bpm. The relationship and agreement between measured and estimated values are shown in Figures 1 and 2. Correlation coefficients were 0.35 and 0.34 for the "220 - age" and "208 – 0.7 x age" equations, respectively ($p < 0.001$). Figure 3 shows the relationship of the volunteers' age with maximum HR measured, and the correlation coefficient was found to be – 0.34 ($p = 0.0008$). Therefore, age was inversely related to HR at exhaustion.

Table 3 - Descriptive statistics of Heart Rate values (mean ± standard deviation) at rest, at exhaustion during GXT, and as a result of prediction equations

Variable	Mean ± Standard Deviation	Variation
Resting HR (bpm)	69.1 ± 9.9	51.0 to 94.0
Measured HRmax (bpm)	145.5 ± 12.5	114.0 to 169.0
"220 – age" (bpm)	152.9 ± 5.1	139.0 to 160.0
Tanaka (bpm)	161.0 ± 3.9	151.3 to 166.0

HR - Heart Rate; Measured HRmax - maximum heart rate reached during graded exercise testing.

Discussion

The exclusion criteria adopted in this study aimed at minimizing any interference of secondary factors in the variable under study. For example, the type or ergometer used, smoking status, gender, use of drugs with negative chronotropic action (especially beta-blockers), and body composition significantly affect measured HRmax[6-8,11]. Therefore, efforts were made to delimit the sample, standardize test conditions, and exclude subjects sensitive to secondary influences.

Volunteers' heart rate increased progressively and

Table 4 - Comparisons between HRmax during GXT and HRmax estimated from the "220 - age" and Tanaka equations (n = 93)

Variable	Mean ± SD (bpm)	Correlation coefficient (relative to HRmax during GXT)
Measured HRmax	145.5 ± 12.5	
"220 – idade" (bpm)	152.9 ± 5.1*	0.34
Tanaka (bpm)	161.0 ± 3.9*,#	0.35

*SD = Standard Deviation; HRmax = Maximum Heart Rate; bpm = beats per minute. * Significant difference relative to measured HRmax. P < 0.001; # Significant difference relative to HRmax derived from the "220 – age" equation. P < 0.001.*

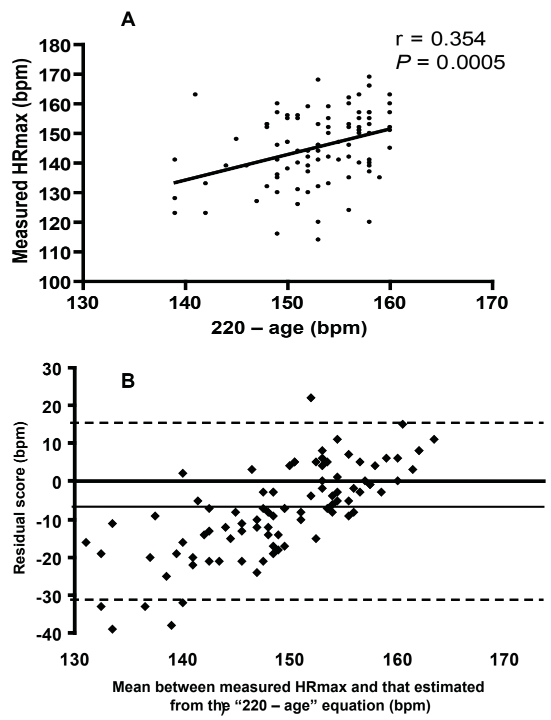

Fig. 1 - *Relationship between measured HRmax and that estimated from the "220 - age" equation. (A) Correlation between values using Pearson's coefficient. Each point indicates individual values. (B) Graphic representation of the mean difference between values (solid line) and 95% confidence interval (broken lines).*

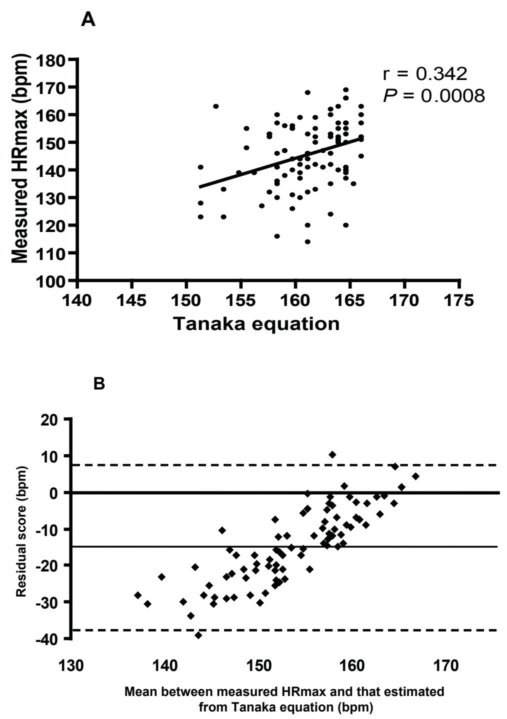

Fig. 2 - *Relationship between measured RHmax and that estimated from theTanaka equation. (A) Correlation between values using Pearson's coefficient. Each point indicates individual values. (B) Graphic representation of the mean difference between values (solid line) and 95% confidence interval (broken lines).*

concomitantly according to increasing exercise intensity during GXT, beginning with a mean value of 69.1 bpm (at rest) and reaching 145.5, on average, at exhaustion. This HR behavior during graded exercise is well-established in the literature, both in young and elderly subjects[15,16]. Some factors influence HR increase during physical exercise, which is indeed all-important for enhancing cardiac output to meet active muscle oxygen demand[20]. Exercise induces considerable acute autonomic adaptations, which greatly affect the cardiovascular system, including the chronotropic function[21,22]. According to Araújo[22], the HR increase observed during the first seconds of exercise, regardless of exercise intensity, is primarily mediated by vagal inhibition (lower level of parasympathetic activity), whereas cardiac sympathetic activity enhances subsequently[21]. Muscle mechano- and metaboreceptors, as well as arterial baroreceptors, are afferent pathways for the cardiovascular control center located in the ventrolateral medulla and play a major role in modulating cardiac chronotropic activity during graded exercise[16].

In our study, HRmax values measured during GXT were significantly lower when compared with those from prediction equations, with a mean difference of 7.4 bpm and 15.5 bpm for the "220-age" and Tanaka's equations, respectively. This finding may have important implications for prescribing exercise intensity for this population. Based on HRmax determined by prediction equations, exercise

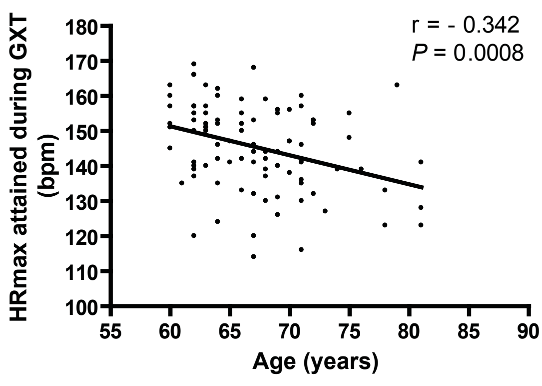

Fig. 3 - *Correation between measured HRmax and volunteers' age. Each point indicates individual values. Pearson's coefficient was used to assess relationships.*

prescription may cause excessive cardiovascular and metabolic stress. In addition to identifying cardiovascular abnormalities[4], the importance of performing exercise stress testing in elderly subjects before they engage in any exercise program is emphasized by these results. Together with the fact that HR based on standard exercise stress tests overestimates training intensity in young[23] and elderly subjects alike[24] when compared with exercise prescription from ergospirometric tests, our results suggest that exercise intensity based on prediction equations is even more overestimated and, thereby, should be viewed cautiously. An important clinical consequence of this finding is the fact that the double product tends to rise disproportionately in relatively high intensities[25], thus increasing the risk of cardiovascular events during physical exercise sessions.

Comparing the results obtained from Tanaka and "220 - age" equations in this sample, the first was found to overestimate HRmax significantly. In fact, these findings were reported by Tanaka et al[13] in the article in which this equation was proposed. In forty-year old subjects, both equations produce identical results; however, at older ages, Tanaka's equation showed higher values for HRmax. Therefore, HRmax identified during GXT was closer to the traditional equation, although a significant statistical difference was found. Using the same prediction approach, earlier reports have pointed to an overestimate of HRmax measured during maximal spiroergometric tests in young[23] and elderly Brazilians[24]. In this regard, considering that the "220 - age" formula has a standard error of 10 a 12 bpm[26] and the mean difference between measured and predicted HRmax was 7.4 bpm, study patients are within the expected limits for this equation. The number of elderly women whose values were under- or overestimated by the "220 - age" and Tanaka's equations is more clearly presented in Figures 1A and 1B, respectively.

Heart rate at exhaustion was, on average, 95.12% of the predicted maximum (220 - age), a finding similar to that of a sample of 100 elderly Brazilians who underwent symptom-limited exercise stress test in a study carried out by Vacanti et al[17], in which HRmax was 95.7 of the age-predicted maximum. Wajngarten et al[24] assessed elderly subjects by cardiopulmonary exercise testing (CPET) using a bicycle ergometer and reported that measured HRmax was, on average, 95% of the age-predicted maximum. Such result is consistent with that of the present study, since Araújo and Pinto[27] demonstrated that there are no significant differences between HRmax measured during treadmill exercise tests and lower-extremity cycle ergometer tests. Their results revealed that accuracy of both equations was questionable in the elderly Brazilians of this sample, corroborating Kindermann et al findings[28], which postulated that age-predicted HRmax is only a standard to estimate the degree of intensity during exercise stress testing and not necessarily identical to HR values reached during maximal exercise.

An invariable consequence of aging is a decline in cardiovascular performance, that is, cardiac output, stroke volume, HRmax, and maximal oxygen uptake decrease[29,30]. In fact, HRmax has shown to be inversely related to age during exercise treadmill test performed by 95 subjects between 19 and 69 years of age[15]. The results of the present study confirm this chronotropism decrease, since a negative and significant correlation was observed between this variable and volunteers' age. These findings demonstrate that even after age 60, exercise-induced tachycardia declines progressively. With aging, cardiac autonomic control seems to be depressed, with a decreasing occurring in cardiac response to sympathoadrenergic stimulation and, consequently, in chronotropic reserve[30].

The lesser degree of exertional tachycardia explains, in part, the reduced capacity to attain maximal cardiac output by the elderly compared with healthy young subjects[30]. This process leads to a concomitant decline in maximal aerobic capacity[31], even in elderly subjects that remain engaged in regular vigorous endurance exercise training[32]. Actually, the estimated mean maximal oxygen uptake found in this sample (22.24 $ml.kg^{-1}.min^{-1}$) is lower than that reported for a group of Caucasian and Hispanic young women (34.1 $ml.kg^{-1}.min^{-1}$), yet similar to that of women 60 years or older[33] (21,5 $ml.kg^{-1}.min^{-1}$). According to the cardiorespiratory fitness classification proposed by the American Heart Association[34], most participants of the present study fall into the regular category, suggesting that estimated VO_2 max was within the range expected for women of the same age group.

We acknowledge some limitations of the present study. Graded exercise testing was performed using standard ergometry, rather than cardiopulmonary stress testing. The ventilatory measures obtained during treadmill exercise yielded relevant information to ensure that the subject being evaluated had indeed reached maximal intensity and, therefore, HRmax. The presence of an oxygen uptake (VO_2) plateau in spite of subsequent increments in workload and high respiratory exchange ratio (R > 1.15) are parameters identified during the ergospirometric test that, coupled with subjective perceived exertion and cardiovascular variables, all indicate that exertion had indeed been maximal[35]. To minimize the possibility of volunteers not reaching maximal exertion, verbal encouragement was given when they neared exhaustion, and perceived exertion[14] was systematically monitored throughout the examination. Conversely, our results provide an important clinical application, since most cardiac clinics in Brazil use conventional exercise stress testing for assessing patients, as well as prescribing exercise intensities[25,36].

Conclusions

In sum, the results of the present study suggest that, in elderly women, the "220 – age" and Tanaka al at[13] prediction equations yield significantly higher HRmax values when compared with those measured during graded exercise testing; hence, they should be viewed with caution when performing exercise stress tests and prescribing physical exercise for this population. On the other hand, the "220 – age" formula has shown relevant clinical value, because predicted HR was within the expected limits for this equation; yet, the elevated standard deviation limits both its accuracy and assessment of physiological individuality. Further studies, preferably using cardiopulmonary exercise testing, are neede to substantiate these findings. Finally, our results also indicate that chronotropic reserve continues to decline after age 60.

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